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FORMULATION OF GRAPHEME-PHONEME CORRESPONDENCE RULES TO AID IN THE TEACHING OF READING.

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STUDY OBJECTIVES WERE--(1) TO ANALYZE 5,000 ENGLISH WORDS TO FIND THE UNDERLYING PATTERNS IN THE SPELLING-TO-SOUND RELATIONSHIPS, (2) TO DEVELOP A MODEL FOR MAPPING SPELLING-TO-SOUND CORRESPONDENCES WHICH NOT ONLY DISPLAYS IN AN ECONOMICAL FASHION THE UNDERLYING SPELLING PATTERNS, BUT ALSO REFLECTS THE SPELLING-TO-SOUND HABITS OF THE MATURE READER, (3) TO FORMULATE ALL THE NECESSARY RULES, BASED UPON THE MODEL, TO PREDICT THE PRONUNCIATIONS OF ALL WORDS ANALYZED, AND (4) TO ABSTRACT RULES AND SUGGESTIONS WHICH COULD AID IN THE TEACHING OF READING. THE DATA AND MODEL WHICH WERE DEVELOPED PROVIDED IMPLICATIONS THAT SIMPLE GRAPHEME-TO-PHONEME CORRELATIONS ARE NOT ONLY UNPRODUCTIVE FOR PREDICTION OF SOUND FROM SPELLING, BUT ALSO ARE IN CONFLICT WITH THE UNDERLYING SYSTEM OF ORTHOGRAPHY. IT WAS RECOMMENDED THAT BOTH MORPHOLOGY AND SYNTAX BE CONSIDERED IN THE SELECTION AND ARRANGEMENT OF WORDS TO BE USED IN THE DESIGN OF TEACHING MATERIALS FOR THE FIRST THREE OR FOUR GRADES. (JM)

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"FORMULATION OF GRAPHEME-PHONEME CORRESPONDENCE RULES TO AID IN THE TEACHING OF READING"

Cooperative Research Project No. S-039

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1964

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TABLE OF CONTENTS

Page
Preface 1
Problem on which the research was focused 2
Objectives and/or hypotheses 3
Related Research 5
Procedure 6
Analyses of the data and findings 31
Conclusions and Implications 46
Appendix A 49
  Table 1 50
  Table 2 51
Appendix B
  Computer Programming 53
Appendix C
  Word List (approx. 5,000 words) 57
Appendix D
  Bibliography 90

LIST OF TABLES

Table 1. Comparison of Pronunciation Transcriptions

Table 2. Word Lists for Regular $\langle -\acute{C}_1VC_2e\rangle$ Patterns

PREFACE

This Final Report for Contract S-039 goes somewhat beyond the original proposal on the basis of which the contract was defined. The original contract called for an analysis of spelling-to-sound relationships in about 5,000 English words. In the course of the work it was found that this corpus was too small for an adequate study, and the sample was extended to approximately 20,000 words. This enlarged corpus in turn required a good deal more work, and to this end the contract was extended for three months, without any additional cost. We are then submitting a report covering work on the much larger list.

Included in this report is a description of a model we have constructed for the analysis of spelling-to-sound relationships and detailed analyses of various spelling-to-sound correlations.

The model and analyses described here form the groundwork for an exhaustive study of spelling-to-sound relationships in approximately 20,000 words which will be completed under U.S. Office of Education Contract No. OE-4-10-206.

All of the material contained in this report is the result of the joint efforts of the Chief Investigator and the Junior Linguist, Mr. R. L. Venezky.

Ruth H. Weir

Stanford
August 1964

4. Problem on which research was focused.

One of the basic processes in reading is the translation from letters to sounds, or, as it is sometimes called, from graphemes to phonemes. The mature adult reader has developed a set of reading habits which include an ability to apply a large number of correspondence rules, although he is generally unable to verbalize the rules he uses. What are these rules, and how do they operate in spoken and written English? This is the basic question on which this research is focused.

For years the teaching of reading has partially depended on "phonics", that is on some correlation of spelling and sound, but no exhaustive study of a large body of material has been available to show just what these correlations in fact are. The original proposal specified a corpus of 5,000 English words to be analyzed (See Appendix C). This sample, however, proved too small for an adequate study, and research on 20,000 words was proposed at a later date. The latter proposal was granted (Contract OE-4-10-206), and findings presented in this report include information based on the larger sample as obtained thus far.

It must be pointed out that this research deals only with the one-way relationship of spelling to sound. While the model and analyses presented here also form the basis for an exhaustive study of sound-to-spelling relationships, such an analysis was not a part of this contract.

5. Objectives and/or hypotheses.

The hypotheses on which this research is based are that English spelling relates not only to phonology, but also to morphology and syntax, and that, when viewed with this understanding, a much higher degree of regularity emerges than does emerge when we confine ourselves to a simple letter-to-sound relationship. To this end we have constructed a model which is based upon three different levels: grapheme, morphophoneme, and phoneme. Before a word is subjected to analysis, it is broken down into its morphemic constituents, since it is our hypothesis that spelling is essentially morphophonemic, hence single morpheme words are our point of departure. It is further hypothesized that hierarchically ordered rules must be applied to map the single morpheme graphemic word onto the morphophonemic level, and then, through the application of further appropriate rules, onto the phonemic level.

The major objectives, then, of this research were to analyze the spelling-to-sound relationships in order to discover not only the basic patterns involved, but also, the levels on which these patterns operate. In dealing with so-called irregular spelling-to-sound relationships, the levels on which the irregularities occurred were also described. This is essential not only for descriptive adequacy, but also for providing an accurate framework upon which the teaching of reading can be based.

The basic data to be analyzed under this contract were obtained by a computer program written by R. Venezky in co-ordination with the Reading Research Project at Cornell University (supported by U.S. Office of Education Grant No. 639). (See Appendix B for the program) The program accepted as input about 20,000 entries selected from the Thorndike-Lorge word count. (1)

Proper nouns, abbreviations and contractions have been deleted from the list. Entries were selected on the basis of frequency of occurrence in running English texts, using the frequency counts in the Thorndike dictionary as a guide. In the dictionary the 20,000 most common words are marked with an integer which ranges from one to twenty to indicate which thousand-bracket the word belongs to. A word marked with a one occurs in the 1,000 most common words in English and a word marked with an integer n, where n is greater than one, occurs in the n-thousand most common words, but not in the (n-1)-thousand most common words. Pronounciations are drawn chiefly from Kenyon and Knott's Pronouncing Dictionary of American English (2), with modifications based upon dialect atlas material for the upper Midwest. Table 1 shows a comparison of Kenyon and Knott with the Thorndike dictionary pronounciations.

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(1) Thorndike, E.L. and I. Lorge, The Teachers' Word Book of 30,000 Words, N.Y. Bureau of Publications, Teachers College, Columbia University, 1944.

(2) J. Kenyon and T. Knott, A Pronouncing Dictionary of American English, Springfield, Mass., G.and C. Merriam Co., 1949.

6. Related Research.

A bibliography of works consulted is included in Appendix E. Specifically, Cornell University's Reading Research Project mentioned earlier provided some of the basis for the work reported on here, as did Fries' notion of "spelling patterns" (17). Discussions with C.F. Hockett on his unpublished research on spelling-to-sound relationships, and communication with N. Chomsky on his, as yet unpublished, work on English Phonology also bear directly on the work reported here.

The efforts of Project Literacy in facilitating discussions of persons interested in related research have proved very useful.

7. Procedure

A. Data Collection

As mentioned earlier, the initial data upon which this study is based were obtained by R. Venezky with the aid of a computer program written for the Control Data 1604 computer (69). This program, written in connection with the Reading Research Project at Cornell University, formed and tabulated spelling to sound correspondences for approximately 20,000 English words (63). Output from this program included tabulations of spelling-to-sound correspondences and word lists for each correspondence. For the present study the program was modified and parts of it rewritten in FORTRAN-63, the computer language selected for the other programming done for this study.

General purpose programs written in FORTRAN-63 were developed to perform the following tasks:

1. Form a blocked dictionary tape from cards or card images. The input records are scanned for illegal characters and grapheme and frequency number counts are taken.
2. Edit a dictionary tape. This program allows dictionary entries to be replaced, deleted, or added.
3. Tabulate grapheme-phoneme correspondences and compile word lists for graphic monosyllables and for the 5,000 most frequently used words in the input dictionary.

4. Form and alphabetize a dictionary of backward spellings from the input dictionary.
5. Form and alphabetize a dictionary of backward pronunciations from the input dictionary.
6. Form and tabulate by number of syllables and by vowels, the vowel phonemes of the words in the input dictionary.

Descriptions of the programs used for these tasks are included in Appendix B.

Using the data from the tabulations and word lists obtained with these programs, an extensive analysis of grapheme-phoneme relationships was made. The backwards dictionaries were used to study English suffixes, while the tabulations of vowel patterns was used for studying the relationship between stress and vowel quality and for tabulating data on phonotactics.

Computer programs have been used only to tabulate the data upon which this study is based. No attempt has been made and no attempt is planned to extend the computing effort to the discovery of grapheme-phoneme patterns.

B. Pronunciations..

Kenyon and Knott's A Pronouncing Dictionary of American English (39) was used, with a limited number of deviations, as the pronunciation guide for this study. The decision to use this guide was based upon the following considerations:

1. A broad transcription of a single, widely spoken American English dialect was desired. The Kenyon and Knott dictionary is at present the best available

(and a reasonably satisfactory) compilation of what is called General American Speech, the most widely spoken dialect of American English. While the transcriptions in the Kenyon and Knott dictionary are not completely phonemic (e.g., [ɝ] and [ɚ] are used for retroflex vowels in murmur and, [n̩] [l̩] and [m̩] are used for syllabics), they more closely approximate phonemic than broad phonetic transcriptions.

2. The Thorndike transcriptions are almost identical to the Kenyon and Knott transcriptions, although the symbols employed are quite different. The major transcription differences are in the handling of syllabic consonants and low and mid back vowels before /r/.

The pronunciations used in this study apply to words in isolation. No attempt has been made to account for the phonological alternations which result from connected speech. In the teaching of reading, such alternations are secondary to the pronunciations of words in isolation.

C. Transcriptions.

1. We work with three levels of stress: primary, secondary, and tertiary (unstressed). This agrees with the Kenyon-Knott transcriptions.
2. The phoneme /ə/ appears in this study in both stressed and unstressed positions. (e.g. but /bə́/, about /əbaút/).

Kenyon and Knott use [ʌ] in stressed positions and [ə] in unstressed positions.

3. The retroflex vowel in such words as bird [bɝd] is phonemized for this study /-ər-/. In Kenyon and Knott, both [ɝ] (stressed) and [ɚ] (unstressed) are employed for retroflexed vowels.
4. In those words in which [ɪ] and [ə] occur in free variation in unstressed positions (e.g. harem, foreign), the Kenyon Knott transcription has been accepted.
5. The contrast of /o/ -/ɔ/ before /r/ has been eliminated, thus merging such pairs as moarning-mourning and hoarse-horse. In Kenyon-Knott this contrast is retained.
6. For the unstable vowel in roof, hoof, cooper, root, broom, room, etc., the Kenyon-Knott transcriptions have been adopted.
7. The /j/ glide occasionally transcribed by Kenyon and Knott between initial alveolar consonants and the high back vowel /u/ has been rejected since it is atypical of GA speech (58). Thus:

Tuesday	/túzdɪ/
new	/nú/
due	/dú/
Susanne	/súzən/

This contrasts with the Kenyon and Knott transcriptions, which have /ju/ as the preferred pronunciation.

D. Analysis.

The types of correspondences which are found in English spelling-to-sound relationships are discussed in this section, along with the model which we have constructed for displaying these correspondences. This material forms the basis for the detailed analyses which are presented in Section 8.

I. Phonological Correspondences

In presenting the phonological patterns we have selected rather arbitrarily the divisions of regular phonemic, irregular phonemic, and phonotactics. In what follows we intend only to show some examples of patterns within these divisions and not give an exhaustive account of each. In all cases phonological correspondences apply to single morpheme words. In the part on morphological correspondences we will talk about polymorphemic words as well. Word in this discussion is defined graphemically --- graphemes being class definitions, related to graphs which appear on a printed page, in a manner analogous to the way that phonemes relate to allophones. In all cases we are discussing words out of context --- that is, as they appear in isolation, and in all cases we are working within a synchronic framework. Where stress is mentioned, we are assuming three levels of stress.

In the category of regular phonemic correspondences we have first invariant patterns, that is, graphemes that have one general pronunciation. regardless of their environments. Of the 2,000-odd occurrences of the grapheme ⟨b⟩, for example, all but a few are pronounced /b/. (There is a general rule that accounts for the geminate consonant clusters like ⟨bb⟩

--see page 24). The graphemes ⟨f,k,m,n,v,y,z⟩ also fit into this class.

The second subdivision of regular phonemic correspondences is variant and in this category there are two further classes, each based upon the conditioning factor that determines the variation. Graphemic environment is generally the most important determiner of the various pronunciations for a single grapheme. The grapheme ⟨c⟩, for example, when it appears before the graphemes ⟨e,i,y⟩ plus consonant or juncture, is pronounced /s/ as in cent, city, and cycle, while in word final position, or before ⟨a,o,u⟩ and any consonant except ⟨h⟩, it is pronounced /k/. The casesof the digraph ⟨ch⟩ and ⟨c⟩ plus front vowel plus vowel will be discussed shortly. (There are a few exceptions to this pattern like cello and facade.)

The position of a grapheme or grapheme cluster in a word -- still a case of graphemic environment -- is also a major conditioning factor. Interconsonantal ⟨a⟩, for example, in monosyllables not ending in ⟨e⟩ is always pronounced /æ/ as in back, bag, band.

The second category of variant regular phonemic correspondences is the stress conditioning category. The patterns for intervocalic ⟨x⟩ are examples of stress conditioning. If the primary stress is on the syllable preceding ⟨x⟩, then the corresponding phoneme consonant cluster is /ks/ (exit, exercise), while if the stress is anywhere else, the cluster is voiced to /gz/ (exert, examine). This follows directly from Verner's Law for the Germanic voiceless spirants. The cases of ⟨x⟩

before a consonant are also regular, but are not stress conditioned.

In many cases, both stress and graphemic environment may be conditioning factors. For example, in most of the words in which the cluster ⟨er⟩ appears in medial position, with primary or secondary stress, three patterns emerge, each depending upon a particular graphemic environment:

(i) If ⟨-er-⟩ is followed by ⟨i⟩ plus another vowel, the pronunciation is /ɪr/ as in *experience*, *period*, *serious*.

(ii) If ⟨-er-⟩ is followed by a vowel plus a consonant or juncture, the pronunciation is /ęr/ as in *merit*, *cherish*, *cemetery*.

(iii)If ⟨-er-⟩ appears before a consonant, the pronunciation is /ər/ as in *assert*, *merchant*, *person*.

The other major subdivision of phonological correspondences is the *irregular class*. This class, though accounting for only a small portion of the total phonological category, receives the greatest attention in educational and popular writings on the general subject of orthography. There are two and possibly three seemingly natural categories for this class. The first contains frequent spellings that have various pronunciations which can only be predicted by knowing the whole word. Most occurrences of the digraph ⟨ch⟩ fit into this class. The corresponding pronunciations /k/,/š/,/č/, while explainable historically, can only be predicted synchronically from the whole word, that is, can only be described by such rules as "⟨ch⟩ in the words --- is pronounced such and such". When we present the model for describing spelling-to-sound correspondences we will show what we believe to be the most economical way of handling such forms.

The second subdivision of the irregular class is composed of such nonce forms as *debt*, *doubt*, *thyme* and *island*. As a general description of this class, "rare-irregularities" should suffice. Number of tokens is what distinguishes this subdivision from the first one mentioned.

It may also be feasible to set up a third subdivision of irregularities to contain those spelling-to-sound irregularities that occur in homonym pairs. We have not looked at enough of these items as yet, however, to know if this can be justified.

In the third major category of phonological correspondences are contained those spelling-to-sound correspondences which can be predicted upon the basis of phonotactics. The /š/ and /č/ pronunciations in *sugar*, *sure*, *mature*, and *bastion*, fit into this category as do the initial pronunciations of *gnat* and *knee*. The rule (with certain conditioning factors which are not mentioned here) that applies to *sugar* and *social* is {s+y+v}→/š/+v. A similar rule accounts for the /č/ in *mature* and *bastion*. ⟨gn-⟩ and ⟨kn-⟩ are unpronounceable initial consonant clusters in English. A general rule (with slight restrictions) which can be applied here is that the initial consonant is dropped in such clusters. This rule also accounts for such clusters as ⟨mn-⟩ *mnemonic*
⟨pt-⟩ *ptarmigan*
⟨psh-⟩ *pshaw*

II Morphological Elements.

The two most commonly mentioned morphemic elements in the orthography are the final ⟨ - (e)s⟩ used as the regular noun plural marker, as the third singular present indicative marker for the verb, and a few other functions, and the regular past tense marker ⟨ -(e)d⟩. Both of these graphemic forms represent more than one pronunciation, yet they also represent single morphemes. There are simple phonotactic rules in English for predicting the pronunciations of these forms, once their morphemic identity is ascertained. Without this information, there is little regularity in their behavior.

Although both the cluster ⟨ch⟩ and the noun-plural ⟨(e)s⟩ have three different pronunciations, there is an important distinction between these two items. In the ⟨ch⟩ case, the pronunciations depend upon the actual words in which the ⟨ch⟩ clusters appear, that is, upon the graphemic level, as mentioned earlier, but the ⟨(e)s⟩ pronunciations depend not upon the graphemic level, but upon the morphophonemic level. The clue to predicting the pronunciation of the noun plural ⟨(e)s⟩ is in the recognition of this morpheme from word final ⟨s⟩ as in stylus, apropos, curious. If the noun plural ⟨(e)s⟩ is not separated from the single morpheme word final ⟨s⟩, most of the regularity in its pronunciation is lost.

The final consonant clusters in the words paradigm, damn, and bomb are morphophonemic spellings. In a pure spelling-to-sound analysis, one is forced to the conclusion that the ⟨g⟩

in paradigm, the ⟨n⟩ in damn and the final ⟨b⟩ in bomb are functionless graphemes. When viewed, though, from a morphophonemic standpoint, the pairs

paradigm -- paradigmatic
damn -- damnation
bomb -- bombardier

reveal a regular morphophonemic alternation that is preserved in the orthography. This consonant pattern is quite common in English. Besides the three examples given, there are, for example

malign -- malignant
design -- designate
sign -- signify
autumn -- autumnal
condemn -- condemnation
hymn -- hymnal

Without the retention of the full consonant cluster in final position, the identity of the common morphemic element in such pairs would be lost on the graphemic level.

Another fairly regular pattern is a voiced - voiceless morphophonemic alternation as is reflected in

house -- houses
north -- northern
south -- southern
worth -- worthy

In these cases, as in the earlier ones cited, morphemic identity is preserved on the graphemic level and the phonemic values attached to the various graphemes can be predicted on the morphophonemic level.

Besides graphemes that take different phonemic values, depending upon morphological criteria, there are occasional spelling differences for the same sound that reflect morphophonemic alternations. One of the most curious is reflected in the words commerce and universe. Both words end in /s/, although the phoneme is spelled with a ⟨c⟩ in one, and with an ⟨s⟩ in another. A good spelling reformer would argue for the elimination of one of these spellings and in doing so would destroy an important morphophonemic clue. Notice the alternation that occurs when the adjective forming suffix /əl/ is added to each: /kəməršəl/ /jùnəvə́rsəl/

In the word in which /s/ is spelled ⟨c⟩, there is an alternation of /s/→ /š/, while in the other there is no such alternation. While two different spellings for the same sound may be irregular from a direct spelling-to-sound standpoint, they may, as in this case, convey information on the morphophonemic level.

A careful study of the morphological elements in the orthography must include an analysis of the various graphemic shapes for the same morpheme -- that is, of graphemic allomorphs. For convenience in presenting examples of these forms we have classed graphemic allomorphs as identical and non-identical. Identical graphemic allomorphs are those forms which have the same spelling as exemplified by the following:

sign	signal	(signify, significance)
civil	civilian	(civility, civilization)

While the pronunciations of some of the vowel graphemes are different within the paradigms, the morphemic shapes are preserved. Whether or not this is desirable for an orthography is not significant here. What is important is the recognition of such morphemic clues.

Nonidentical graphemic allomorphs can be further subdivided into classes of regular and irregular. The regular ones are those whose various spellings can be predicted from orthographic rules. Thus the forms:

traffic	trafficking
die	dying

are regular in that the orthographic changes can be predicted by reference to the orthography rules included in the back of most desk dictionaries. The ⟨k⟩ is inserted after the ⟨c⟩ when followed by any of the vowels ⟨i,e,y⟩ to preserve the /k/ pronunciation. The ⟨ dy-⟩ spelling follows a regular rule for adding ⟨-ing⟩ to words ending in ⟨-ie⟩.

Further examples of regular graphemic allomorphs can be seen in such pairs as

syntax	syntactic
galaxy	galactic
decide	decision
divide	division
elide	elision
grief	grieve
proof	prove

Irregular graphemic allomorphs consist of patterns which do not follow regular orthographic rules. Of course, there is always the chance that new coinings and borrowings will follow an irregular pattern to the point of making it regular. Many of the words that optionally double a final consonant before suffixes fit into this category. Examples are such forms as *counsel(l)ing*, and *travel(l)ing*. The spelling of *space* and *spatial* is another example of an irregular graphemic allomorph.

Another type of grammatical conditioning is dependent on form class. Examples are the pronunciations of initial ⟨th-⟩, and the vowel pronunciations in the ending ⟨-ate⟩. In the case of ⟨th-⟩, functors have the voiced inter-dental spirant while *non-functors* have the voiceless pronunciation.

Final ⟨ate⟩ generally has two pronunciations: /-et/ in verbs -- *translate*, *deflate*, *duplicate*, and /-ɪt/ in adjectives and nouns -- *syndicate*, *duplicate*, *frigate*, *affricate*.

III *A Model for Spelling - to - Sound Correspondences*.

It should be evident from the foregoing material that any model that attempts to describe spelling-to-sound correspondences must account for both phonemic and morphemic patterns. Such a model must also handle irregularities, that is, it must show on what level the irregularity occurs. For example, given the irregular forms *arcing* and *facade*, one necessary condition for the model is that it distinguish the different types of irregularity which are reflected in the pronunciations of the grapheme ⟨c⟩ in these words. The irregularity in *arcing* enters with the irregular formation of the graphemic allomorph ⟨arc-⟩ before a suffix beginning with ⟨i⟩. This is an exception to a general orthographic rule that requires a ⟨k⟩ to be inserted in this environment, as was shown earlier in the example of *trafficking*. *Facade* is irregular in the basic graphemic word - ⟨c⟩ before ⟨a⟩ is pronounced /s/ instead of the usual /k/. This is an exception to a basic environmentally conditioned grapheme →

phoneme correspondence. There are other conditions that must be met in our description which will become evident later. In essence, the model that we will present shortly is an economical way to account for the workings of the current orthography which also predicts certain things about reading habits and regularity - or the lack of regularity.

Exactly how much this model will predict about reading habits, we cannot say at present. Some work in progress at the present time hopefully will shed some light upon this problem. We are guided to a limited degree, however, in searching for regular patterns, by the notion of reading habit. Thus, in accounting for the various pronunciations of initial ⟨ch⟩, one could simply state that in words derived from Old English or borrowed from Old French before such and such a time, the pronunciation is /č/, and so on. But such a rule obviously does not reflect the habits of the average reader.

The selection of appropriate units perhaps best reflects the attempt - and some of the uncertainties - of using reader habits as a guide to rule formation. For example, the choice of a rule that says that the initial grapheme cluster ⟨rh⟩ is mapped into the morphophoneme {r} (the mapping rules will be explained shortly) rather than the rule that ⟨h⟩ after initial ⟨r⟩ is mapped into a zero morphophoneme is based upon a notion of how a reader operates. We do not really know that this is true - but we predict that it is - that is, we predict that initial ⟨rh⟩ is perceived as a unit rather than as two discrete units, ⟨r⟩ and ⟨h⟩.

In this example, either rule could be chosen on the basis of economy or simplicity. That is, for a pure competence model, either rule would suffice. But obviously, we are not interested in competence alone. If we were, we would attempt to formulate any rule possible based upon graphemic shape or upon morphology to show as much regularity as possible in the spelling-to-sound relationship. Rules of the type "grapheme ⟨x⟩ in words of length y, or in words having no graphemes that open to the left is mapped into morphophoneme Z" - could be formulated and certainly would add regularity in many cases, but we are sure that most people would agree that such a rule could serve no useful purpose.

The actual model that we have constructed is based upon three different levels: grapheme, morphophoneme, and phoneme. For the present we are using the term phoneme to represent elements on the phonological level; broad phonetic may be a more desirable form, but a clumsy one as well. The term morphophoneme is used in an extremely broad sense here. What is meant by the morphophonemic level is an intermediate level between grapheme and phoneme that contains what are traditionally called morphophonemes plus additional things that deviate slightly from the traditional concept of the morphophoneme. What these other things are and how much they deviate from the classical view will be apparent shortly and should offer no obstacle for understanding what we are attempting to do.

Single morpheme graphemic words are mapped, by the application of appropriate rules, onto the morphophonemic level, and then through the application of appropriate morphophonemic rules onto the phonemic level.

Rules are ordered lists of statements of the following general shapes:

Rule 1. ⟨x⟩ (Y) (Z) → {p}
Rule 2. {p} (W) → {g}
Rule 3. {g} → /r/

Rule 1 reads "grapheme (or grapheme cluster) x in position y (initial, medial, or final in a word) and in the environment z is mapped into the morphophoneme p." Either y or z may be omitted. Z may be such statements as:

"after grapheme g"
"in all cases"
"in functors"
"ELSE"

Rule 2 reads "morphophoneme p in environment w is mapped into morphophoneme g."

Rule 3 reads "morphophoneme g is mapped into phoneme r."

Rules are always ordered and generally the last rule in any group applies to all cases not covered by the previous rules. This is signalled by the environmental marker ELSE. An inventory of graphemic shapes contains all those forms which have irregular grapheme → morphophoneme correspondences.

Thus, the word ⟨debt⟩ would be contained in this directory with the information that ⟨b⟩ was mapped into zero.

Polymorphemic words are first broken into their constituent morphemic units and each of these is then mapped into morphophonemic strings. Thus, the form ⟨climactic⟩ would first be broken into ⟨climax⟩ + ⟨-ic⟩ and then these forms would be mapped into the morphophonemes:

⟨climax⟩ + ⟨-ic⟩ → {klaɪmæks$_1$} + {-ɪk}
→ {klaɪ̀máktɪk}
→ /klaɪ̀mǽktɪk/

Although several steps have been omitted, the general form of the mappings should be evident. Morphophonemic rules for the addition of the {-ɪk} suffix account for the alternation of {ks} → {kt} and the stress shift.

Stress placement is accounted for on both the graphemic and the morphophonemic levels. We have made a general assumption on the placement of primary stress in a mono-morphemic word and on the stress patterns which occur before and after the syllable with primary stress. Further, there are rules for predicting deviations from the general pattern, and finally, there is a list of forms in which the stress pattern cannot be predicted. For simplicity we include these forms in the graphemic allomorph dictionary.

These stress-placement rules are applied on the graphemic level after the word has been divided into its constituent graphemic allomorphs, but before any other rules are applied. The actual rules and the lists of exceptions have not been worked out completely as yet, nor do we expect to complete them very soon. We have some patterns which do work well, and also some notions that may or may not work. One brief example may illustrate our work in this area.

In the intervocalic ⟨x⟩ patterns (graphemic x) the corresponding morphophoneme cluster is either voiced or not, depending upon the placement of stress, as mentioned earlier. All of the words in our corpus with stress not on the syllable before x begin with the grapheme cluster ⟨ex-⟩. This includes about 25 forms. (Exact, exalt, exaggerate, exempt, and so on). Therefore, one rule which we can write, with some restrictions, is that mono-morpheme words with intervocalic x that do not begin with ⟨ex-⟩ have tonic stress on the syllable before x. This accounts for about 80 out of 88 forms. Of the remaining eight, all of which begin with ex-, six are tri-syllabic and, in these it appears that the last syllable requires secondary stress, therefore preventing the penultimate syllable from having tonic stress. We believe that the actual rule that applies here will be more complex than this, but nevertheless this appears to be at least part of the rule. The remaining two words, exile and exit, pattern differently from the general case and possibly for this reason have both the voiced and voiceless pronunciations.

Stress rules on the morphophonemic level account for stress shifts with affixation, such as the rule that requires penultimate stress with the addition of the adjective-forming suffix /ɪk/. The exceptions to this rule, like choleric, are simply listed as exceptions; that is, the rule that immediately precedes the penultimate stress rule will say that in such words there is no stress shift.

To aid in distinguishing graphemic allomorphs, we are constructing a graphemic allomorph dictionary that contains the irregular graphemic allomorphs and the base forms to which they are related. Connected with the graphemic allomorph directory are orthographic rules that apply to affixation.

This model does require a nearly complete description of English morphophonemics. At the present time we are working on a large number of problems in this area. We hope to benefit by the work being done by other investigators on English morphophonemics which can be fitted into this model. However, in order to demonstrate the model further, following are two examples showing the application of ordered rules on various levels. One example is that of geminate consonant clusters, the other that of the grapheme ⟨t⟩.

Geminate consonant clusters offer several special problems to the description of spelling-to-sound correspondences. The first problem is in distinguishing geminate clusters within morphemes from those that occur across morpheme boundaries. (In forms like hidden, and programming, where the geminate clusters result from orthographic conventions, the cluster properly belongs to one morpheme and therefore is not an inter-morpheme cluster as viewed here.) When the cluster occurs across a morpheme boundary the two consonants are treated as morpheme final and initial respectively. This is one reason for requiring the recognition of morpheme boundaries in the spelling-to-sound description.

Within a single morpheme further problems arise. Certain clusters like ⟨-bb-, -tt-⟩ have only one pronunciation and therefore could be described on the graphemic level by a general rule. The cluster ⟨-cc-⟩, however, cannot be handled in this manner since it can correspond to either /k/ or /-ks-/ (*accommodate* vs. *accede*). While a special rule could be written to cover this case on the graphemic level, such a rule would duplicate the previously written rules for ⟨-c-⟩ since the choice between /-k-/ and /-ks-/ depends upon the pronunciation of the second ⟨-c-⟩ as predicted by the regular ⟨-c-⟩ rules.

The simplest solution to this problem is to relate each element of a geminate cluster to a morphophoneme, using the usual grapheme→morphophoneme rules, and to write one general morphophonemic rule for reducing geminate morphophonemic consonant clusters to single items. Thus,

⟨accommodate⟩ → {ækkammodet}
→ {əkámədèt}
→ /əkámədèt/
⟨accede⟩ → {æksid}
→ {ækssíd}
→ /æksíd/

This system requires only one rule for clusters within morphemes, while any other system would require at least two. Under any system, however, irregular forms like *bacchanal*, *sapphire*, *exaggerate*, and *suggest* have to be handled as exceptions.

A further exception - that of the voiced or voiceless pronunciations of medial ⟨-ss-⟩ may add further weight to the morphophonemic approach. It appears that there is some pattern-ing, based upon stress placement and possibly vowel quality, for predicting whether the sibilant is voiced or not. These rules appear to apply to both ⟨-ss-⟩ and ⟨-s-⟩ in intervocalic position, and it would therefore only be an unnecessary duplication to handle each of them separately. In the morphophonemic approach the cluster reduction statement would be applied first, and the general rule for determining whether or not the morphophoneme {-s} is voiced would follow: Thus

⟨dissolve⟩ → {dɪssɑlv}
→ {dɪsálv}
→ {dɪzálv}
→ /dɪzálv/
⟨lesson⟩ → {lɛsson}
→ {lɛson}
→ {lɛ́sən}
→/lɛ́sən/

In handling geminate consonant clusters across morpheme boundaries, the inventory of graphemic allomorphs makes for a simplification of the overall description. Under this system, one general rule on the morphophonemic level would be sufficient for handling these cases, since each graphemic allomorph is mapped into separate strings of morphophonemes which are then combined. Since graphemic allomorphs are part of the general description, no additional rules are necessary here. For example,

⟨midday⟩ → ⟨mid⟩+⟨day⟩
→ {mɪ́d}+{dè}
→ {mɪ́d+dè}
→ /mɪ́d+dè/

Rules for the Grapheme ⟨t⟩

The grapheme ⟨t⟩ occurs in a large number of graphemic patterns. If we consider only grapheme→phoneme relationships, at least five different correspondences can be found (not including the ⟨th⟩ patterns).

{Ø}	hasten, ballet
{ž}	equation
{č}	bastion, creature
{š}	aviation, militia
{t}	tone, matrix

In describing these various correspondences on the basis of the model that has been set up, two distinct problems must be solved. One is to account for the correspondences on the proper level, and the other is to find the most general rules possible to account for the correspondences. In some cases, the most general rule may be a list of words in which the correspondence occurs. This, of course, is the most undesirable rule possible, but in most cases it simply represents the state of the art. In some cases it may represent the failure of the investigators to see a pattern that actually exists.

The words in which ⟨t⟩ correspondes to {Ø} fall into several groups. In the largest group are the French borrowings like:

ballet
challet
crochet
debut
depot
filet
sachet
savant

One is tempted to formulate a rule based upon final ⟨-et-⟩

(leaving depot, savant and debut as exceptions). Due to the following forms, however, such a rule has no validity:

fidget	mallet	toilet
hatchet	ratchet	wallet

Another, better possibility is in considering the placement of stress: The rule

⟨t⟩ (f) (disyll. words ending in -et with ultimate stress) → {∅}

covers all cases except depot, savant and debut which must be handled by the rule

⟨-t⟩ depot → {∅}
savant
debut

The forms fasten, hasten, glisten, moisten, chasten and listen represent a pattern which fits both the graphemic and morphophonemic levels. In all of these forms the rule

⟨t⟩ (V+sten#) → {∅}

could be applied to account for the behavior of ⟨t⟩. The existence of haste and chaste, however, require that for consistency these two be treated as bimophemic words: Thus.

⟨hasten⟩ → ⟨haste⟩+⟨en⟩
→ {hest}+{ən}
→ {hésən}
→ /hésən/

In this case a morphophoneme {t_1} is established which follows the following rule:

{-t_1 + # → {t}
else → {∅}

The final group in which ⟨t⟩ corresponds to zero is in words like apostle, castle, and nestle. A single rule

⟨t⟩ (-stle) → {Ø}

will account for these.

Therefore, the ⟨t⟩ - to - zero correspondences fall into two classes: a regular graphemic one, and a regular morphophonemic one.

In words like aviation and militia, a general rule could be used to map {t + V⟩ directly into {s} in the appropriate graphemic environment. The existence of the parallel forms social, judicial and ocean with ⟨c + V⟩ → {s} and abrasion, adhesion and illusion with ⟨s + V⟩ → {z} indicate that more general rules can be written. The actual rules which appear to be the most economical for these cases are the following:

1. ⟨t⟩ (M) (-G_1t + V_1 + V) → {s} $G_1 \neq$ s or x
2. ⟨t⟩ (ELSE) → {t} $V_1 \neq$ u   Vs = stressed vowel
3. {s} + {y + Vs} (polysyllabic) → {ši + Vs}
4. {s} + {y + V} (ELSE) → {š + V}
5. {t} + {y + V} → {č + V}

Rule 1 maps ⟨t⟩ into {s} when it is not preceeded by ⟨s⟩ or ⟨x⟩ (bastion, celestial, etc.) and not followed by ⟨u⟩ (mature, etc.), in all other cases is mapped into {t}. Rules 3 and 4 separate such pairs as partial and partiality, while rule 5 accounts for the /č/ pronunciations.

For completeness, rules 3, 4, and 5 have to be generalized to cover the {zy} → {ž} and {dy} → {ǰ} cases and a single rule has to be written to account for the irregular form *equation*.

8. Analysis of Data and Findings.

A complete and exhaustive analysis of the relationship of spelling-to-sound, as suggested by the model described in section 7, must account for the following:

1. Graphemic allomorphs
2. Grapheme-to-morphophoneme correspondences
3. Morphophonemic alternations
4. Morphophoneme-to-phoneme correspondences.

Since the existing orthography is, for the most part, a morphophonomic system, it is essential both for a theoretical analysis and for the practical problem of teaching reading to recognize the morphemic constituents of orthographic words. The various vowel pronunciations and different stress patterns which correspond to the same graphemic shape can more easily be predicted from a knowledge of the morphemic components than they can from the orthographic word alone.

Identical graphemic allomorphs, as exemplified by damn, damnable, damnatory offer no problems of recognition.

The identity of non-identical graphemic allomorphs rests heavily upon a knowledge of regular orthographic rules for affixation. Such rules have been adequately discussed in a number of publications (74) and therefore are not a concern of this project.

For the purposes of this study, the most important spelling-to-sound relationships are those of graphemes to morphophonemes. These relationships are crucial for relating English orthography to the spoken language, and therefore are of greatest importance in the teaching of reading. The morphophonemic alternations and morphophoneme-to-phonemic relationships, while equally important for our theoretical analysis, represent habits which the illiterate speaker of English generally has. These habits, therefore, do not need to be relearned in order to attain literacy.

Within this grapheme-to-morphophoneme system we have worked separately with bound affixes (prefixes and suffixes) and single morpheme free forms (stems). An exhaustive analysis of consonant correspondences and a partial analysis of vowel correspondences (grapheme-to-morphophoneme) are included in this section. The remainder of the vowel correspondences and the bound affix analysis will be completed under contract OE-4-10-206.

The following analysis of grapheme-to-morphophoneme relationships applies to the graphemic consonants found in the 20,000 word corpus. A graphemic consonant in this study includes all occurrences of the graphemes ⟨b, c, d, f, g, h, j, k, l, m, n, p, q, s, t, v, x, z⟩, occurrences of ⟨r⟩ which are not preceded by ⟨a, e, i, o, u, or y⟩ in monomorphemic words, restricted occurrences of ⟨w⟩ and ⟨y⟩ as described in the material which follows, and ⟨u⟩ when preceded by ⟨q⟩.

All correspondence rules except those for digraphs and trigraphs ending in ⟨h⟩ are grouped according to the first letter of the grapheme cluster. (A consonant cluster is a continuous string of one or more consonants.)

The groups are presented in alphabetical order; the rules within each group are ordered according to the sequence in which they must be applied. Rules for digraphs and trigraphs ending in ⟨h⟩ are grouped under the letter ⟨h⟩.

As mentioned earlier, these rules cover only the grapheme-to-morphophoneme correspondences.

Morphophoneme-to-morphophoneme and morphophoneme-to-phoneme rules account for many of the more common so-called irregularities in the orthography. For example, ⟨z⟩ is pronounced /z/ all cases except when preceded by ⟨t⟩, where it is pronounced /s/ as in quartz. While a grapheme-to-morphophoneme rule could account for this, it is not necessary since the cluster /tz/ does not exist in English. A general phonotactic rule can account for the devoicing of /z/ in this position. General phonotactic and morphophonemic rules also account for the phonological correspondences of ⟨mb⟩ in bomb, bombing, bombadier; ⟨kn⟩ in knee, and various other consonant clusters. A detailed account of all these rules will be given in a future report.

Irregular grapheme-to-morphophoneme correspondences generally appear as the first rules in any sequence. [An irregular correspondence is one in which the correspondence is either an exception to a general rule or one in which the correspondence is so rare that no general rule can be applied to it.]

Following the irregular correspondences are the regular correspondences which are ordered so as to have the least number of rules possible. The final rule in each group applies to all cases not covered by the previous rules. While these rules adequately describe the grapheme-to-morphophoneme correspondences, it may be possible to gain further economy through generalization of series of rules. Future work will be devoted in part to this.

Consonant Correspondences

⟨b⟩

⟨b⟩ (L) → {Ø}
debt
doubt
subpoena
subtle

⟨b⟩ (ELSE) → {b}

⟨c⟩

⟨cch⟩ } → see ⟨h⟩
⟨ch⟩

⟨c⟩ (cello) → {č}

⟨c⟩ (victual, czar, indict) → {Ø}

⟨c⟩ (facade) → {s}

⟨c⟩ (before ⟨i, y, e⟩) → {s}

⟨c⟩ (ELSE) → {k}

⟨d⟩

⟨d⟩ (handkerchief) → {Ø}

⟨dg⟩ (ALL) → {j}

⟨dj⟩ (ALL) → {j}

⟨d⟩ (ELSE) → {d}

⟨f⟩

⟨f⟩ (of) → {v}

⟨f⟩ (ELSE) → {f}

⟨g⟩

⟨gg⟩ (exaggerate) → {j}

⟨gg⟩ (suggest) → {g }

⟨gh⟩ See ⟨h⟩

⟨gn⟩ (-ette , L) → {ny}
cognac
poignant

⟨g⟩ (-g̅ne , L) → {Ø}
seraglio

⟨g⟩ (M) (L) → {ž}
bourgeois
camouflage
corsage
garage
lingerie
loge
massage
mirage
prestige
protege
regime
rouge
sabotage

⟨dg⟩: see ⟨d⟩

⟨ng⟩: see ⟨n⟩

⟨gh⟩: see ⟨h⟩

⟨g⟩

⟨g⟩ (L) → {g}

anger
auger
beget
begin
begirt
bogey
conger
eager
finger
fogey
forget
gear
get
geyser
gibbon
giddy
gift
gig
giggle
gild
gill
gilt
gingham
give
gizzard
hunger
linger
meager
monger
porgy
renege
target
tiger
together
yogi

⟨g⟩ (goal) → {ǰ}

⟨g⟩ (-ir + C) → {g}

⟨g⟩ (-e, -i, -y) → {ǰ}

⟨g⟩ (ELSE) → {g}

⟨ch⟩

⟨sch⟩ (schism) → {s}

⟨sch⟩ (schist, schwa, seneschal) → {š}

⟨sch⟩ (eschew) → {sč}

⟨sch⟩ (ELSE) → {sk}

⟨cch⟩ (ALL) → {k}

⟨tch⟩ (ALL) → {č}

⟨ch⟩ (L) → {ø}

fuchsia
yacht
drachm

⟨ch⟩ (archer) → {č}

⟨ch⟩ (-l, -n, -r) → {k}

⟨ch⟩ (-ar, polysyllabic) → {k}

⟨ch⟩ (L) → {k}

ache
catechism
chameleon
chaos
character
chasm
chemi-
chiropodist
choir
choler
cholera
choral
chord
chorus
dichotomy
echo
epoch
eucharist
eunuch
hypochondria
lichen
machination
mechanical
orchestra
orchid
pentateuch
psych-
stomach

⟨ch⟩ (L) → {š}

cache
chagrin
chaise
chalet
challis
chamois
champagne
champaign
chandelier
chanty
chaperon
charade
charivari
charlatan
chassis
chauffeur
chauvinism
chef
chemise
cheroot
chevalier
chevoit
chevron
chicanery
chiffon
chivalry
chute
cliche
crochet
echelon
machine
mustache
ricochet
sachet
stanchion

⟨ch⟩ (ELSE) → {č}

⟨gh⟩

⟨gh⟩ (F) (hough) → {k}

⟨gh⟩ (L) → {f}

clough
cough
draught
enough
laugh
rough
slough
sough
tough
trough

⟨gh⟩ (I) (ALL) → {g}

ghastly
ghetto
ghost
ghoul

⟨gh⟩ (L) → {g}

aghast
burgh
dinghy
sorghum
spaghetti

⟨gh⟩ (ELSE) → {Ø}

⟨ph⟩

⟨ph⟩ (shepherd) → {p}

⟨ph⟩ (ELSE) → {f}

⟨rh⟩

⟨rh⟩ (ALL) → {r}

⟨sh⟩

⟨sh⟩ (ALL) → {š}

⟨th⟩

⟨th⟩ (thyme) → {t}

⟨th⟩ (isthmus, asthma) → {. }

⟨th⟩ (ether) → {θ}

⟨th⟩ (L) → {θ_1}

bath
mouth
north
south
worth

⟨th⟩ (I) → (functors) → {ð}

⟨th⟩ (M) (-er,-e#) → {ð}

⟨th⟩ (L) → {ð}

bequeath
farthest
farthing
fathom
furthest
heathen
logarithm
rhythm
smooth
swarthy
with

⟨th⟩ (ELSE) → {θ}

⟨wh⟩

⟨wh⟩ (I) (L) → {h}

who
whole
whom
whoop
whore
whose

⟨wh⟩ (ELSE) → {hw}

⟨h⟩

⟨h⟩ (L) → → {Ø}

exhale
exhaust
exhibit
exhilarate
exhort
fahrenheit
heir
herb
honest
honor
hour
humor
nihilism
silhouette
vehement
vehicle

⟨h⟩ (F) (ALL) → {Ø}

ah
eh
halleluiah
hurrah
pharaoh

⟨h⟩ (ELSE) → {h}

⟨j⟩

⟨j⟩ (marijuana) → {h}

⟨j⟩ (bijou) → {ž}

⟨j⟩ (ELSE) → {ǰ}

⟨k⟩

⟨k⟩ (ALL) → {k}

⟨l⟩

```
⟨l⟩  (C+{-alve} + #)  →  {Ø}
        {-alk }
        {-alf }
        {-alm }
```

⟨l⟩ (colonel) → {r}

⟨l⟩ (ELSE) → {l}

⟨m⟩

⟨m⟩ (accompt, comptroller) → {n}

⟨m⟩ (ELSE) → {m}

⟨n⟩

⟨n⟩ (kiln) → {Ø}

⟨n⟩ (ELSE) → {n}

⟨p⟩

⟨p⟩ (receipt) → {Ø}

⟨ph⟩ → see ⟨h⟩

⟨ps⟩ (corps) → {Ø}

⟨p⟩ (ELSE) → ⟨p⟩

⟨q⟩

⟨qu⟩ (L) → {k}

liquor　　queue
piquant　　turquoise

```
⟨qu⟩  (-{ue  } + #)  →  {k}
        {e   }
        {et  }
        {ette}
        {ee  }
```

⟨qu⟩ (ELSE) → {kw}

⟨r⟩

⟨rh⟩ → see ⟨h⟩ rules

⟨V+r⟩ → see vowel rules

⟨r⟩ (ELSE) → r

⟨s⟩

```
⟨ssh⟩}  →  see ⟨h⟩ rules
⟨sh⟩
```

⟨ss⟩ (L) → {z}

dessert　　possess
dissolve　　scission
scissors

⟨s⟩ (L) → {ž}

as　　his
has　　is
was

⟨s⟩ (cynosure) → {s}

```
⟨s⟩  (M)  {-i + V      -}  →  {z}
          {-u + V/C-}
```

⟨s⟩ (ELSE) → {s}

⟨t⟩

⟨th⟩ → see ⟨h⟩
⟨t⟩ (L) → {Ø}

depot
debut hautboy
savant

⟨t⟩ (F) (-et) → {Ø}

⟨t⟩ (M) (-sten / -stle) → {Ø}

⟨t⟩ (equation) → {z}

⟨t⟩ (M) $(-G_1 t + V_u + V)$ → {s}

⟨t⟩ (ELSE) → {t̂}

G = any grapheme except ⟨s⟩ or ⟨x⟩

V_u = any vowel except ⟨u⟩

⟨v⟩

⟨v⟩ (ALL) → {v}

⟨w⟩

⟨wh⟩ see ⟨h⟩

⟨wr⟩ (I) (ALL) → {r}

⟨w⟩ (L) → {Ø}

answer two
coxswains sword

⟨w⟩

⟨w⟩ (I) (ALL) → {w}

⟨w⟩ (M) ({a-- / be- / re-} + w + V) → {w}

award bewail
aware beware
reward

⟨w⟩ (ELSE) → vowel cluster

⟨x⟩

⟨x⟩ (I) (ALL) → {z}

⟨x⟩ $(-V x V-, V x C_{-h})$ → {ks}

C_{-h} = any consonant except h

⟨x⟩ (F) → {ks}

⟨x⟩ (ELSE) → {gz}

⟨y⟩

⟨y⟩ (I) (ALL) → {y}

⟨y⟩ (M) (beyond, lawyer) → {y}

⟨y⟩ (ELSE) → vowel cluster

⟨z⟩

⟨z⟩ (rendezvous) → {Ø}

⟨zz⟩ (mezzo, pizza) → {ts}

⟨z⟩ (ELSE) → {z}

Vowel Patterns

The patterns which follow are part of a preliminary analysis of vowel clusters which begin with ⟨a⟩. Patterns for ⟨a⟩ through ⟨aɪr⟩ apply to the basic 5,000 word corpus which is included in Appendix C of this report. Patterns for ⟨ar⟩ through ⟨ay⟩ apply to the complete 20,000 word corpus. The following tentative morphophonemic rules have also been developed and should be considered in connection with the grapheme-to-morphophoneme rules which follow.

1. {ǣl} + {m} → {ā} + {m}

   This accounts for such forms as alms, balm, calm, palm, and psalm.

2. {æ} (swam) → {æ}

   This is an exception to the rule which follows.

3. {ǣ} (w + ǣ + C) → {a}

   This accounts for the vowel alternation which occurs between {w} and any consonant. (e.g., quality, want, swamp) An identical shift in place of articulation towards the back of the mouth occurs with {a} between {w} and {r} as in quarry. ({a} (w + ar) → {ɔ}). A more general rule probably can be written to cover both-of-these cases.

4. {æ}_ ({-l + V̄ }) → {ɔ}

   V̄ is any non-vocalic unit (consonant or juncture). This accounts for forms like walnut, ball, halt, and walk.

The rule ⟨a⟩ (unstressed) → {ə} will be included in the general rule ⟨V⟩ (unstressed) → {ə} which will cover all unstressed vowel graphemes. (Another rule is needed to change {ə} → {ɪ} before velar stops.) These rules will be developed further after each vowel grapheme is analyzed separately.

⟨a⟩ stressed (primary or secondary)

⟨a⟩ (L) → {ɛ}

any many

⟨a⟩ (- +C+(C)+e⟩ see final ⟨e⟩ rules

⟨a⟩ (-tion, -sion) → {e}

⟨a⟩ (L) → {e}

acorn
agency
agent
ancient
angel
apron
bacon
basin
basis
capable
chamber
danger
famous
fatal
favor
fragrance
haven
label
labor
major
manger
mason
naked
native
nature
paper
patience
patriot
potato
sacred
savior
taper
tomato
vacant
vapor
waver

⟨a⟩ (ELSE) → {æ}

⟨a⟩ (unstressed) → {ə}

- - - - - -

⟨ah⟩ (ah, hurrah) → {a}

⟨aɪ⟩ (unstressed) → {ɪ}

⟨aɪ⟩ (aisle) → {aɪ}

⟨aɪ⟩ (L) → {ɛ}

again against said

⟨aɪ⟩ (ELSE) → {e}

⟨aɪr⟩ (ALL) → {ɛ}

stressed ⟨ar(r)⟩

⟨ar(r)⟩ (L) → {ar}
are
marijuana

⟨ar(r)⟩ (L) → {ær}

chariot carrion marionette
clarion lariat

⟨ar(r)⟩ → {ɛṙ}

area harem polaris
garish parent

⟨ar(r)⟩ $\left(\begin{array}{l}-C\\-\#\end{array}\right)$ → {ar}

⟨ar(r)⟩ (M) $\left(\begin{array}{l}-y\ \#\\-i+V\\-e\ \#\end{array}\right)$ → {er}

⟨ar(r)⟩ (-V+C) → {ær}
er#
age#

unstressed

⟨ar(r)⟩ → {ar}

⟨au⟩ (gauge) → {e}

⟨au⟩ (L) → {ae}

aunt draught laugh

⟨au⟩ (L) → {au}

sauerkraut umlaut

⟨au⟩ (L) → {o}

chauffeur
chauvinism
hautboy
mauve

⟨au⟩ (ELSE) → {ɔ}

⟨aur⟩ (stressed) → {ɔr}

⟨aur⟩ (ELSE) → {ər}

⟨aw⟩ (ALL) → {ɔ}

⟨awr⟩ (stressed) → {ɔr}

⟨awr⟩ (unstressed) → {ər}

⟨ay⟩ (L) → {aɪ}

aye bayou cayenne

⟨ay⟩ (quay) → {i}

⟨ay⟩ (stressed) → {e}

⟨ay⟩ (unstressed) → {ɪ}

Final ⟨e⟩ Patterns

I. ⟨-C_1 V C_2 e⟩ patterns

A. Regular correspondences for V

⟨a⟩ → {e}

⟨e⟩ → {i}

⟨i⟩ → {aɪ}

⟨y⟩ → {aɪ}

⟨o⟩ → {o}

⟨u⟩ → {u}

B. Irregular V correspondences ordered by C_2

1. C_2 = ⟨c⟩

C_1 ⟨-a⟩ (unstressed) → {ɪ}

furnace
menace
necklace
palace
pinnace
populace
solace
surface

C_2 ⟨-i⟩ (police, caprice) → {i}

C_3 ⟨-i⟩ (unstressed) → {ɪ}

C_4 ⟨-u⟩ (unstressed) → {ɪ}

2. C_2 = ⟨d⟩

D_1 ⟨-a⟩ (L) → {æ}

bade
forbade

D_2 ⟨-a⟩ (Facade) → {a}

3. C_2 = ⟨f⟩

F_1 ⟨a⟩ (cafe) → {æ}

4. C_2 = ⟨g⟩

G_1 ⟨a⟩ (L) → {a}

barrage
camouflage
corsage
garage
massage
mirage
sabotage

G_2 ⟨a⟩ (unstressed) → {ɪ}

G_3 ⟨e⟩ (allege) → {ɛ}

G_4 ⟨e⟩ (protege) → {ə}

G_5 ⟨e⟩ (L) → {ɪ}

college
privilege
renege
sacrilege

G_6 ⟨i⟩ (prestige) → {i}

G_7 ⟨i⟩ (vestige) → {ɪ}

5. C_2 = ⟨l⟩

L_1 ⟨-a ⟩ (morale) → {-æ }

L_2 ⟨-a⟩ (gunwale) → {-ə}

L_3 ⟨-a⟩ (finale) → {-a}

L_4 ⟨-e⟩ (ukulele) → {-e}

L_5 ⟨-e⟩ (clientele) → {-ɛ}

L_6 ⟨i⟩ (L) → {i}

automobile
bastile
castile

L_7 ⟨i⟩ (unstressed) → {ɪ}

L_8 ⟨-o⟩ (hyperbole) → {-o}

L_9 ⟨-u⟩ (capsule) → {-ə}

6. C_2 = ⟨-m-⟩

M_1 ⟨-a⟩ (sesame) → {-a}

M_2 ⟨-i⟩ (regime) → {i}

M_3 ⟨-o⟩ (come, some) → {ə}

7. C_2 = ⟨-n-⟩

N_1 ⟨-i⟩ (L) → {i}

bromine
chlorine
crusine
fluorine
gabardine
gasoline
grenadine
libertine
limousine

(con't)

machine
magazine
margarine
marine
messoline
morphine
nectorine
nicotine
prestine
praline
quarantine
ravine
routine
sardine
tangerine
tontine
tricotine
vaccine
vaseline

N_2 ⟨i⟩ (L) → [ɪ]

adamantine
carmine
crinoline
destine
determine
discipline
doctrine
engine
examine
famine
feminine
gelatine
hyaline
illumine
imagine
intestine
jasmine
lupine
masculine
medicine
passerine
rapine
saccharine
turbine
urine

N_3 ⟨-o⟩ (one, done, none) → [-ə]

N_4 ⟨-o⟩ (gone) → [-ɔ]

N_5 ⟨-u⟩ (fortune) → [-ə]

8. C_2 = ⟨-p-⟩

P_1 ⟨-i⟩ (recipe) → [-ɪ]

P_2 ⟨-o⟩ (Europe) → [-ə]

9. C_2 = ⟨-r-⟩

R_1 ⟨-a⟩ (are) → [a]

R_2 ⟨-a⟩ (ELSE) → [ɛ]

R_3 ⟨-e⟩ (L) → [ɛ]

ere where there

R_4 ⟨e⟩ (were) → [-ə]

R_5 ⟨-o⟩ (extempore) → [-ə]

R_6 ⟨u⟩ (unstressed) → [ə]

10. C_2 = ⟨-s-⟩

S_1 ⟨-a⟩ (unstressed) → [ə]

S_2 ⟨-i⟩ (valise) → [-i]

S_3 ⟨-i⟩ (L) → {-ɪ}

arrise
mortise
premise
promise
treatise

S_4 ⟨-o⟩ (whose, lose) → {-u}

S_5 ⟨-o⟩ (purpose) → {ə}

11. C_2 = ⟨-t-⟩

T_1 ⟨-a⟩ (nouns, adj.) → {-ɪ}

T_2 ⟨-e⟩ (fete) → {-e}

T_3 ⟨-i⟩ (elite) → {-i}

T_4 ⟨-i⟩ (L) → {-ɪ}

apposite
composite
define
favorite
granite
hypocrite
infinite
opposite
requisite
respite

T_5 ⟨-u⟩ (minute) → {ɪ}

12. C_2 = ⟨v⟩

V_1 ⟨-a⟩ (have) → {-æ }

V_2 ⟨-a⟩ (octave) → {-ɪ}

V_3 ⟨-i⟩ (L) → {ɪ}

give live olive

V_4 ⟨-o⟩ (L) → {ə}

above
dove
glove
love
shove

V_5 ⟨-o⟩ (move, prove) → {-u}

C. Regular correspondences for ⟨e⟩

⟨e⟩ (-c_1 VC_2e) → {∅}

D. Irregular correspondences for ⟨e⟩

	{I}			{e}
adobe	extempore	hike	simile	cafe
coyote	facsimile	hyperbole	ukulele	protege
epitome	finale	sesame	recipe	

9. Conclusions and implications.

The analysis of data and model presented in sections 7 and 8 of this report contain a number of implications for the teaching of reading. We hope to have demonstrated above all that simple grapheme-to-phoneme correlations are not only unproductive for the prediction of sound from spelling but also are in conflict with the underlying system of the orthography. If the function of the teaching of reading is to establish productive habits which relate to the underlying patterns of the orthography rather than to base instruction on statistical correlations, then both morphology and syntax must be considered in the development of reading materials. This should not be construed as a suggestion to teach morphology and syntax in the first three or four grades where reading is normally taught, but rather as a recommendation for the selection and arrangement of words to be used in the design of teaching materials. We know that the child entering the primary grades has a good command of the basic morphological and syntactic patterns of his native language. Berko [1], Strickland [61]) To teach for example the pronunciations of hen, cat match and also hens, cats, matches as whole units is superfluous. The child has already learned the correct plural allomorph to be used with each stem. However, what he has to learn is the graphemic shapes of the noun plural marker so that he does not confuse such pairs as

⟨hens⟩ and ⟨hence⟩ in reading.

A considerable amount of work remains to be done before the material presented in this report can be adapted to the teaching of reading. Some general notions, however, can be advanced at present. The most important one is that the major emphasis in teaching the relationship between spelling and sound should center on the grapheme-to-morphophoneme patterns. These represent totally new habits which must be obtained in order to read; the morphemic and syntactic patterns are in general already part of the child's language habits. The grapheme-to-morphophoneme patterns should not be viewed as rules to teach as such but rather as indicators of regularly and irregularly spelled words that is of words which have high transfer value and words which have low or negative transfer value for reading of other words. Obviously words which are included in rules (e.g. ⟨c⟩ (facade)→{s}) have low transfer value because they contain either exceptions to general patterns or rare and mostly unproductive correspondences.

By following through correspondences on the morphophonemic level general patterns which apply to seemingly dissimilar words can be readily found. A morphophonemic rule for the correspondence {sy}→{š} for example applies to such words as sure, sugar, nation, social, and controversial. Whether or not this rule can be translated into any meaningful teaching procedures is of course not a linguistic question but rather a pedagogical one and will probably require some experimentation before the answer is found. What is important from our standpoint is that somewhere within the separate rule chains which map each of these words into their phonemic representations the same general rule appears.

As was pointed out earlier, the analysis presented here is preliminary and incomplete. In addition to refining and generalizing the rules which are presented here, future work will concentrate on stress prediction, vowel patterns and affixation. We are, however, satisfied with the over all approach which we have taken and feel that this work will be fruitful both for theoretical linguistics and for the teaching of reading.

APPENDIX A

TABLE 1

Thorndike	IPA	Example	Thorndike	IPA	Example
a	æ	bat	o̲	ą (1)	watch
ā	e	date	ō	o	so
a	ɛ	air	ô	ɔ	jaw
ä	a (1)	far	oi	ɔɪ	toy
b	b	bat	ou	au	how
ch	tʃ	chin	p	p	pail
d	d	date	r	r	run
e	ɛ	bet	s	s	sit
ē	i	see	sh	ʃ	shirt
ėr	ɝ	bird	t	t	tap
f	f	further	th	θ	thin
g	g	game	TH	ð	further
h	h	home	u	ʌ	sun
i	ɪ	pity	u	ʊ	full
ī	aɪ	while	u	u	tooth
j	dʒ	edge	ū	ju	use
k	k	cat	v	v	vase
l	l	ball	w	w	with
m	m	man	y	j	yet
n	n	chin	z	z	using
ng	ŋ	sang	zh	ʒ	vision
			ə	ə	about

---

(1) The symbol a will be used in this report for IPA ɑ.

TABLE 2

Word Lists for Regular $\langle -C_1VC_2e \rangle$ Patterns

⟨B⟩

bake
astrolabe
imbibe
bribe
scribe
tribe
lobe
globe
robe
microbe
probe
cube
tube

⟨C⟩

face
lace
place
mace
carapace
ice
suffice
nice
spice
adduce
seduce
produce
truce

⟨D⟩

decade
barricade
fade
spade
accede
impede
centipede
decide
confide
hide
explode
mode
erode
include
rude
allude

⟨F⟩

chafe
strafe
safe
fife
life
rife
wife

⟨G⟩

cage
gage
page
sage
oblige
refuge
huge
deluge

⟨K⟩

bake
cake
shake
make
bike
like
pike
strike
coke
joke
smoke
rebuke
duke
fluke

⟨L⟩

bale
scale
gale
whale
bile
imbibe
domicile
profile
while
dole
nole
mole
pole
parole
molecule
ridicule
schedule
mule

⟨M⟩

came
dame
name
scheme
theme
supreme
extreme
sublime
rime
time
dome
home
chrome
perfume
volume
resume
rhyme
enzyme

⟨N⟩

bane
hurricane
profane
plane
serene
kerosene
convene
combine
dine
define
phone
alone
hormone
immune
tune
opportune

⟨P⟩

cape
escape
scrape
crepe
pipe
ripe
strife
scope
hope
antelope
dupe
stupe
type

⟨R⟩

sincere
here
adhere
dire
fire
sapphire
core
chore
galore
allure
manure
secure

⟨S⟩

base
case
phrase
obese
these
manganese
precise
merchandise
demise
those
close
diagnose
fuse
abuse
muse

⟨T⟩

abate
placate
abdicate
complete
obsolete
mete
dynamite
ignite
unite
note
promote
wrote
commute
impute
brute

⟨V⟩

shave
gave
brave
eve
five
alive
connive
cove
drove
strove

⟨Z⟩

amaze
craze
graze
trapeze
ostracize
prize
size
doze
froze
analyze
paralyze

APPENDIX B

A. Coding Language

The selection of FORTRAN-63 was based upon the following considerations:

1. The FORTRAN-63 compiler, besides operating under the standard 1604 monitor system, is one of the most efficient compilers available in terms of compiling speed and object code efficiency. This guarentees a savings in computer expenses over most other programming languages.
2. The source language allows the programmer to buffer input and output, using any size physical records (BUFFER IN/OUT statements). Since most of the tasks performed for this study are limited by computer input/output speeds, the buffering facility provides a significant savings in computer expenses.
3. The source language allows character manipulation in core (ENCODE/DECODE statements) and, with the facility for TYPE OTHER arithmetic, allows efficient bit/byte manipulations.
4. FORTRAN-63 is reasonably compatible with the FORTRAN languages implemented for other computers, thus allowing easy conversion to other computers if necessary. Since FORTRAN is the most common programming language in use in this country, almost every general purpose computer manufactured

in the United States has a FORTRAN compiler.

5. FORTRAN-63 has excellent features for mathematical computations, thus facilitating the computing of percentages and averages.

A number of other languages were investigated, including COBOL; ALGOL, SLIP, IPL-V, JOVIAL, and NELIAC. None of these, however, compared favorably with FORTRAN for the programming tasks anticipated. After a thorough comparison of the various languages and computers available, it was decided that the combination of the CDC 1604, FORTRAN-63 and an experienced programmer offered the highest probability of doing the programming efficiently and at a minimum cost. While languages like COBOL or COMIT may be easier for inexperienced programmers to code than FORTRAN, the slow execution speeds and restricted source codes of these languages make the cost of using them prohibitive.

B. List of Programs

All programs are composed of two or more subroutines, one of which handles input buffering and general process control. The programs described below are referred to by the name of their input buffering routines.

VOCALE: Forms grapheme-phoneme correspondences and output one record for each correspondence.

SPELLING: Tabulates statistics and forms word lists for the sorted grapheme-phoneme correspondences.

UPDATE2: Adds, deletes, or replaces dictionary entries.

Different subroutines are used to restrict the tabulations and listings to the following corpora:

(1) Complete 20,000 word list

(2) First 5,000 words

(3) Graphic monosyllable

SYLLABLE: Abstracts vowel patterns, reverses phoneme strings, and counts the number of syllables in a word.

BAKWRDS: Reverses the spelling of dictionary entries.

BLK200: Blocks 7 word dictionary records into 700 word logical records.

LISTFIV: Lists dictionary entries whose frequency counts are ≤ 5.

APPENDIX C

abandon
abandoned
abhor
abide
ability
able
aboard
abode
abolish
abound
about
above
abroad
absence
absent
absent
absolute
abundance
abundant
accent
accent
accept
access
accident
accomodate

accompany
accord
according
accordingly
account
accursed
accursed
accuse
accustom
ache
achieve
acknowledge
acorn
acquaint
acquaintance
acquire
acre
across
act
action
active
actual
add
addition
additional

address
adjoin
admiral
admiration
admire
admission
admit
adopt
adoption
adore
adorn
advance
advantage
adventure
advertise
advice
advise
afar
affair
affect
affection
affectionate
affirm
afflict
affliction

afford
afright
afraid
after
afternoon
afterwards
again
against
age
agency
agent
ago
agony
agree
agreeable
agreement
agricultural
agriculture
ah
ahead
aid
aim
air
airy
aisle

alarm
alas
alight
alike
alive
all
allegiance
alley
allow
allure
almighty
almost
alms
alone
along
aloud
already
also
altar
alter
although
altogether
always
am
amaze

amazedly
amazement
ambassador
amber
ambition
ambitious
amend
amendment
amid
among
amount
ample
amuse
amusement
an
ancestor
anchor
ancient
and
angel
anger
angle
angry
anguish
animal
ankle
anniversary

announce
annoy
annual
anon
another
answer
ant
anxious
any
anybody
anyone
anything
anyway
anywhere
apart
apartment
apiece
apparel
appeal
appear
appearance
appetite
applause
apple
application
apply
appoint

appointment
approach
approve
apron
apt
arch
arctic
are
area
argue
argument
arise
ark
arm
armor
army
arose
around
arouse
arrange
arrangement
array
arrest
arrival
arrive
arrow
art

article
artificial
artist
artistic
as
ascend
ash
ashamed
ashore
aside
ask
asleep
aspect
ass
assail
assault
assemble
assembly
assert
assign
assist
assistance
associate
association
assume
assurance
assure

astonish
astonishment
at
ate
athletic
atmosphere
attach
attack
attain
attempt
attend
attendance
attendant
attention
attentive
attic
attire
attitude
attorney
attract
attraction
attractive
attribute
audience
august
aunt
author

authority
automobile
autumn
avail
avenge
avenue
average
avoid
await
awake
awaken
aware
away
awe
awful
awhile
awoke
ax
axe
babble
babe
baby
back
backward
bacon
bad
bade

bag
bait
bake
baker
balance
ball
balm
banana
band
banish
banishment
bank
banker
banner
banquet
bar
barbarous
barber
bard
bare
bargain
bark
barley
barn
baron
barrel
barren

barrier
base
bashful
basin
basis
basket
bat
bath
bathe
battery
battle
bay
be
beach
bead
beak
beam
bean
bear
beard
bearer
beast
beat
beautiful
beauty
became
because

become
bed
bedroom
bee
beef
been
beer
beet
beetle
befall
before
beforehand
beg
began
beggar
begin
beginning
beguile
begun
behalf
behave
beheld
behind
behold
being
belief
believe

bell
bellow
belong
beloved
below
belt
bench
bend
beneath
benefit
bent
berry
beseech
beside
besides
best
bestow
betray
better
between
beware
beyond
bible
bibliographic
bicycle
bid
big

bill
billow
bind
birch
bird
birth
birthday
bishop
bit
bite
bitter
black
blackbird
blackboard
blacksmith
blade
blame
blank
blanket
blast
blaze
bleat
bleed
blend
bless
blessing
blether

blew
blind
bliss
block
blood
bloody
bloom
blossom
blot
blow
blue
bluff
blunt
blush
board
boast
boat
body
bog
boil
bold
bolt
bone
bonnet
book
boon
boot

booth
border
bore
born
borrow
bosom
both
bother
bottle
bottom
bough
bought
bound
boundary
boundless
bounty
bowels
bower
bowl
box
boy
brace
bracelet
braid
brain
brake
branch

brand
brass
brave
bravery
bread
breadth
break
breakfast
breast
breath
breathe
bred
breech
breed
breeze
brethren
briar
bribe
brick
bride
bridge
bridle
brief
bright
brighten
brilliant
brim

bring
brink
brisk
broad
broke
broken
brood
brook
broom
brother
brought
brow
brown
brownie
bruise
brush
brute
bubble
bucket
bud
buffet
bug
bugle
build
builder
building
built

bulb
bulk
bull
bullet
bunch
bundle
bung
bunt
burden
bureau
burial
burn
burr
burst
bury
bush
bushel
business
bust
busy
but
butcher
butter
butterfly
button
buy
buzz

by
bye
cabbage
cabin
cabinet
cable
cake
calendar
calf
call
calm
came
camel
camp
campaign
can
canal
candidate
candle
candy
cane
cannon
cannot
canoe
canst
canvas
cap

capable
capacity
cape
capital
captain
captive
capture
car
card
care
career
careful
careless
cargo
carpenter
carpet
carriage
carrier
carry
cart
carve
case
cash
cast
castle
cat
catch

cathedral
catholic
cattle
caught
cause
cave
cease
cedar
ceiling
celebrate
celebration
celestial
cell
cellar
cement
cemetery
censure
cent
center
central
century
ceremony
certain
certainly
certificate
chaff
chain

chair
chairman
chalk
chamber
champion
chance
change
channel
chapel
chapter
character
characteristic
charge
chariot
charity
charm
chart
charter
chase
chaste
chat
chatter
cheap
cheat
check
cheek
cheer

cheerful
cheese
cherish
cherry
chest
chestnut
chick
chicken
chief
child
childhood
children
chill
chime
chimney
chin
china
chip
chirp
chocolate
choice
choir
choke
choose
chop
chose

christian
church
cigar
circle
circuit
circular
circumstance
circus
citizen
city
civil
clad
claim
clamor
clang
clap
clash
clasp
class
classic
clatter
clause
claw
clay
clean
cleanse

clear
cleave
clerk
clever
clientele
cliff
climate
climb
clime
cling
clip
cloak
clock
close
closet
cloth
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elsewhere
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formerly

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frown

frozen
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offend
offense

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opposite
opposition
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overthrow
overturn
overwhelm
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party
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pastor
pasture
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patron
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peep
peer
peg

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pencil
peninsula
penny
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pepper
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perch
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perfection
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perilous
period
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permanent
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permit
perpetual
perplex
persecute

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yourself
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APPENDIX D

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